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13 May 1963

STATINTL [redacted]
Washington, D. C.

STATINTL [redacted]

The scheduled date for the report on Phase I of the Viewer Study is May 24th. Since my letter to you of May 7th, I have discussed this with Dr. [redacted] and there is no problem of meeting that schedule. STATINTL

However, as you know, the study is showing that the proposed approach is likely to be difficult and expensive to achieve, and that other methods or even radical departures may have to be considered.

The work now going on consists of resolution measurements on a system which would be limited to ten or twelve times magnification, but [redacted] would like to have some extra time to explore other approaches which might prove effective. STATINTL

I would like to ask that the report on Phase I be postponed to June 17, 1963, to permit a few other ideas to be considered and included in it. This will in no way involve any increase in funding. The direction the study has taken has precluded the kind of expenditures originally planned, and the funds are more than adequate to take care of the extra work now proposed.

Please let me know your wishes on this proposed extension of date so I can advise [redacted] accordingly. STATINTL

Yours very truly,

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[redacted]

Technical Director

DECLASS REVIEW by NIMA/DOD

7 May 1963

STATINTL [redacted]
Washington, D. C.

STATINTL [redacted]

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Enclosed is a copy of "Progress Report No. 1 on a Feasibility Study for a High Resolution Rear Projection Viewer" (24 April 1963) as prepared by [redacted] of [redacted] our subcontractors for this portion of the work. STATINTL

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I visited [redacted] on April 30, 1963, and discussed this report with [redacted] STATINTL

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[redacted] They had prepared a light source, imaging lens, field lens and crossed diffraction grating setup to get a first crude look at what is happening in the proposed system. With a green filter in the light path and a target in the focal plane, it was evident that a good quality of image was coming through. The pupil was larger than expected, probably due to leakage in the filter, but as magnification was increased to 10 or 12X, it became too small to be useful.

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We discussed some of the means proposed for extending the pupil; prominent among these was the method suggested by [redacted] in his report, i.e. preparing specially ruled gratings. While it is too early in the study to come to firm conclusions, it is likely that the specially ruled grating would be very expensive to prepare in the size required, and there would be considerable mechano/optical difficulties in replica duplication and alignment. This is being looked into further.

Other means of extending the apparent pupil size are being thought about, such as by means of rotating wedges and oscillating mechanisms.

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As we discussed when I visited you on May 3rd, I have asked [redacted] to consider any means possible of achieving the optical qualities associated with virtual images, whether or not these means are related to diffraction screens, with the purpose of bringing these to your attention, and getting investigation authorized by you, where promise is apparent.

I will keep you informed of progress.

[redacted] STATINTL

Enclosure

Progress Report #1 on a Feasibility Study for a High Resolution Rear Projection Viewer

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1. Of all the difficulties pointed out in [redacted] proposal of 2 October 1962, by far the greatest problem is the requirement that the viewer have an exit pupil of at least 3 1/2" diameter. The continuously variable magnification and the resolution requirements do require study, but are within the state of the art. It has been proved, however, that the large exit pupil is theoretically incompatible with magnifications larger than about 4 1/2. This proof is based on the assumption that the viewer contains only refracting and reflecting elements in its imaging channel. Consequently the only way of circumventing this proof and going beyond a 4 1/2x magnification is to introduce optical elements of a different nature: diffusing-, diffracting-, amplitude splitting- or otherwise.

   In this progress report we shall report on our investigations regarding gratings.

2. The upper limit imposed by the theory on the diameter of the exit pupil of a 50x system is 0.4". The value that can be attained in practice must be assumed to be not much more than half this value: a 0.2" diameter exit pupil requires a relative aperture of F/1, or, more exactly, a numerical aperture of 0.5.

   A grating, placed in the real image plane of this system, will multiply this exit pupil into a linear array of exit pupils, which, when properly aligned, may be considered as one larger composite exit pupil. With two gratings at right angles and a square primary exit pupil it is in principle possible to create a composite pupil of 3 1/2" square. This requires a total of 17 diffraction images: the zero order plus eight orders on each side.

   The number of lines per inch in this grating is easily calculated. The eighth order must be deviated by an angle subtending the radius of the exit pupil; assuming a distance between pupil and image of 10" and a wavelength of .55 microns this leads to a grating with a period length of 40 microns, which means 1000 lines to the inch.

3. Within one period the structure of the grating is as yet undetermined: in each period the transmission and the phase retardation must in principle be considered as functions of position. This "period profile" must be chosen such that the intensity in each order is the same, or very nearly so. Mathematically this may be expressed as follows:

   Let $f(x)$ be a complex valued function, defined in one (and so in each) period, whose modulus never exceeds unity. The modulus of this function represents the amplitude transmission as a function of position, its argument represents the phase retardation. For convenience we may renormalize this interval of one period to run from -1/2 to +1/2.

We write f(x) as a fourier series:

$$f(x) = \sum_{-\infty}^{+\infty} c_n e^{2\pi i n x}$$

$$c_n = \int_{-1/2}^{+1/2} f(x) e^{-2\pi i n x} dx.$$

With this notation, the intensity in the n^{th} diffraction order is determined by the squared modulus of the n^{th} fourier coefficient. Thus the problem of finding a grating profile that will solve the problem at hand is reduced to the following procedure: for C_{-8} through C_{+8}, we choose 17 arbitrary numbers with modulus 1; for the other fourier coefficients we choose any arbitrary numbers. We determine f(x) as the fourier series composed of this set of coefficients, and, after proper renormalization, we have found one of many grating profiles that will satisfy the requirements. In this class of profiles we now have to determine a solution which maximizes the energy flow into the orders that we use and minimizes the energy flow into the orders that we do not use.

This latter half of the problem is fraught with mathematical difficulties. It is possible to solve it under some restrictive assumptions, in order to find physically meaningful answers it will, however, be necessary to program the problem on an electronic computer.

4. Even if the mathematical problem described in the preceding section were solved, the practical value of the solution would leave much to be desired. We shall demonstrate this with a simplified example. Suppose that we wish to diffract the same amount of energy in the zero order and in the two first orders; and no energy in any other order. In this case the optimum function f(x) is:

$$f(x) = \frac{1 + 2i \cos 2\pi x}{\sqrt{5}}$$

This means that the intensity transmission of the grating must fluctuate according to:

$$\frac{1 + 4 \cos^2 2\pi x}{5}$$

and the phase retardation (in radians) must fluctuate according to:

$$\arctan(2 \cos 2\pi x).$$

However interesting this may be, it is impossible to rule a grating to these specifications with the methods that are currently in use to fabricate gratings.

The actual case of 17 orders with equal energy will lead to functions that are a good deal more complicated: We feel that several years of research and development will be necessary to produce a grating which optimizes the mathematical problem defined in section 4, i.e. which optimizes the energy transmission under the constraint that the energy deflected in all used orders is the same.

5. When we drop the condition that the energy transmission be optimized we can attack the problem from the other end; given the known techniques of fabricating gratings, how can we achieve our goal of equal energy in all used orders? This problem does not allow a straight forward mathematical approach; we have, however, considered two solutions:

A. The radiation pattern as a function of direction (φ) of a narrow slit with width d is essentially given by:

$$\left[\frac{\sin\left(\frac{2\pi}{\lambda} d \sin\varphi\right)}{\frac{2\pi}{\lambda} d \sin\varphi}\right]^2$$

In this formula λ is the wavelength of the light and φ is the angle between the direction of observation and the direction of the incident light.

When we make a grating consisting of narrow slits spaced at 40 microns, this formula shows that the slits must be very narrow indeed to acquire a uniform illumination throughout the pupil: a slit width of 0.4 microns will limit the intensity drop off to the edges to 20%. (Incidentally it may be mentioned that the formula given above shouldbetter not be used for such narrow slits: a more rigorous argument leads, however, to essentially the same result). This slitwidth, with the 40 micron spacing, shows that the grating is opaque for 99% of the surface. The energy transmission will be minimal, and the fact that we have to use two of these gratings crossed rules out this solution completely.

B. A normal grating is always made with a certain blaze: it must for most applications have the property of diffracting most of the light in one particular order. This blaze is achieved in a manner as indicated in

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fig. 1 for a reflection grating; the surface of every grating line is a tiny tilted mirror, and most of the energy is diffracted into a direction given by the normal laws of reflection. In the same manner a transmission grating may be considered as an array of narrow prisms. The shape of the grooves is controlled by the shape of the cutting diamond.

This technique might be extended to solve our problem. First we rule, with a 40 micron spacing a set of narrow lines with one particular blaze. These grooves are so narrow (say for instance 2 microns) that in between two lines there is still a great amount of space untouched. In this space we rule a second set of lines, again with a 40 micron spacing, but with a different blaze. This process may be repeated a number of times. Fig. 2 elucidates this concept. The proper alignment of the partial gratings will present appreciable difficulties, and so will attaining the right blaze in every partial grating. These difficulties are aggravated by the fact that the ruling must be done in an aluminum or gold film; consequently this mastergrating is opaque and replica's of it must be used in the viewer. Retaining the right blaze in taking the replica's will be very hard.

6. Before we can come to a conclusion about the feasibility of the approach sketched in the preceding section it will be necessary to do some experimental work with existing gratings. We are in the process of setting up some bread board experiments in order to get a feeling for the contrast that can actually be achieved with methods of the type described. Only if the gain in viewer performance is appreciable we feel that the approach of section 5B should be persued; the fabrication difficulties will be considerable. A different approach might be the use of a random grating; this concept, however, comes dangerously close to utilizing a diffusing screen. If diffusing screens are used, we prefer a compactly designed front projection system.

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April 24, 1963

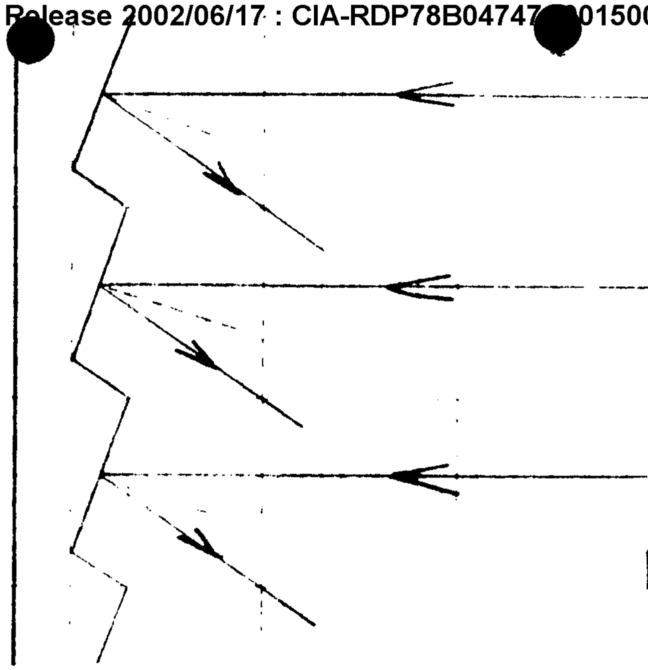

FIG 1.

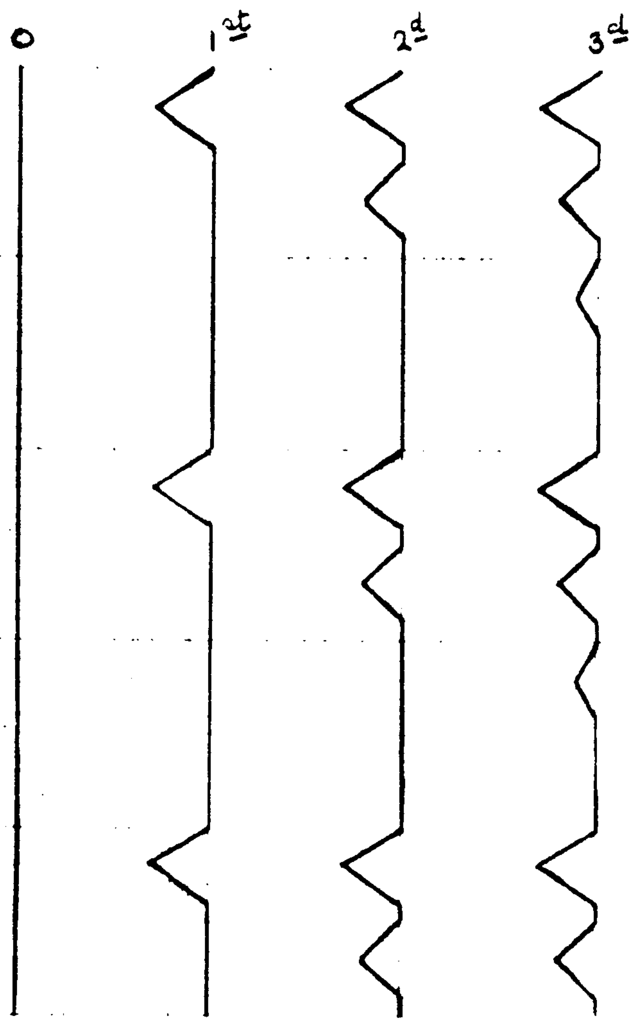

FIG 2.

GRATING BLANK AFTER 1st, 2d & 3d RULING.